BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W.   WASHINGTON, D.C. 20024

SUBJECT: Influence of Weight Changes on AS-503 Structural Longitudinal Mode Shapes and Frequencies
Case 320

DATE: September 10, 1968

FROM: H. E. Stephens

ABSTRACT

An AS-503 24-mass longitudinal model was used to examine the effect of changes in payload and S-IC propellant weights on longitudinal mode shapes and frequencies at a flight time of T+120 seconds.

It was found that changes in payload weight could noticeably influence the S-IC engine gimbal acceleration response in the first and second modes. For example, a +10% increase in SM weight decreases the engine gimbal acceleration by 2.4% at the first mode natural frequency and increases it by 2.9% at the second mode natural frequency. Changes in payload weight will make a significant change in the payload response in the third and fourth body modes. Only minor changes will occur in the longitudinal frequencies due to changes in payload weight.

(NASA-CR-73539) INFLUENCE OF WEIGHT CHANGES ON AS-503 STRUCTURAL LONGITUDINAL MODE SHAPES AND FREQUENCIES (Bellcomm, Inc.) 23 p

N79-72337

Unclas
00/18 11324

FF No. 6

CR-73539
(NASA CR OR TMX OR AD NUMBER)

(CODE)

(CATEGORY)

[redacted]

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MEMORANDUM FOR FILE

INTRODUCTION

The MSFC 24-mass longitudinal model of the AS-503 structure has been used to investigate the effect of changes in payload and S-IC propellant weights on the longitudinal mode shapes and frequencies. The 24-mass model was used rather than a more complex one such as the Boeing model in order to reduce computer time. In establishing a baseline for the parametric study, the Boeing and 24-mass model results were compared and the 24-mass model modified to force greater agreement with the Boeing results, particclarly for payload critical higher modes. The 24-mass model, along with the method of solution and comparison with the more complex Boeing model results, is given in Appendix A.

PARAMETRIC VARIATIONS

Parametric variations were performed for a time of flight of T+120 seconds and are given in Table I.

TABLE I

Mass Number (Figure 1A)	Item	Maximum Variation (%)
3,4	SM	+10
6	LM	+10
18,19	S-IC Propellant	+5

New mode shapes and frequencies were calculated for each variation. Because the response varies widely from mode to mode, a comparison only of the changes in the mode shape would be misleading. For comparison purposes, the total response due to the rigid body plus first four modes was calculated over the frequency range of 3.9 to 9.9 cps by:

$$\ddot{X}_i = \sum_{n=0}^{4} \frac{h_{gn}\; h_{in}}{(M_{eqn})\;(g)} \quad \frac{S^2}{(S^2 + 2\zeta_n\; \omega_n\; S + \omega_n^2)}$$

where:

$\ddot{X}_i$ = acceleration at point of interest in g's/lb force at S-IC engine gimbal block reference

n = mode number

h_{gn} = modal coordinate at gimbal for n<u>th</u> mode

h_{in} = modal coordinate at point of interest for n<u>th</u> mode

M_{eqn} = 1 lb-sec^2/in (all mode shapes normalized to this value of equivalent mass)*

g = gravitation constant

$S = j\ \omega$

ω_n = natural frequency of n<u>th</u> mode

ζ_n = damping ratio (ζ_1 = .008, ζ_2 = .009, ζ_3 = .013 and ζ_4 = .014)

ACCELERATIONS

Acceleration versus frequency plots were made for three points of interest (S-IC engine gimbal, LM, and CM) and are shown by Figures 1 to 3. The acceleration response shown at each frequency is the summation of the contribution from the rigid body plus each of the first four modes.

The baseline acceleration values and percentage change at the frequencies of each of the first four modes are summarized in Table II; the following general statements can be made:

a. An increase in the SM or LM weight decreases the response at the S-IC engine gimbal in the first mode, increases it in the second mode, and makes little difference in the third and fourth modes.

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*Mode shapes have been normalized to the same equivalent mass to permit a direct comparison. Normalization to maximum amplitude is sometimes used, but does not give a direct comparison of response.

TABLE II

T+120 SECONDS

SUMMARY OF ACCELERATION CHANGES DUE TO WEIGHT VARIATIONS (SEE FIGURES 1 TO 3)

RESPONSE AT NATURAL FREQUENCY OF:	BASELINE ACCELERATION VALUE (g'S/LB AT GIMBAL	% CHANGE IN BASELINE VALUE FOR:		
		+10% SM WT	+10% LM WT	+5% S-IC PROP.
	GIMBAL ACCELERATION			
1ST MODE	2.41×10^{-5}	-2.4	-7.1	-0.7
2ND MODE	$1.88Z10^{-5}$	+2.9	+8.2	-8.2
3RD MODE	1.95×10^{-6}	+0.6	+1.4	-4.3
4TH MODE	1.56×10^{-6}	+0.2	+0.8	-3.9
	LM ACCELERATION			
1ST MODE	9.29×10^{-5}	-1.3	+3.0	-1.8
2ND MODE	6.43×10^{-5}	-1.2	+8.1	-2.0
3RD MODE	1.28×10^{-6}	+425	+160	-10.4
4TH MODE	1.92×10^{-6}	+195	-155	-0.8
	CM ACCELERATION			
1ST MODE	7.24×10^{-5}	--	-2.5	-1.5
2ND MODE	3.76×10^{-5}	+0.4	+3.0	-1.1
3RD MODE	3.75×10^{-7}	-12.5	+130	-2.7
4TH MODE	6.82×10^{-6}	-9.0	+0.8	-1.1

b. Small LM or SM weight changes can make a large percentage change in the LM and CM response in the third and fourth modes. However, it is noted that the response in these two modes is one to two orders of magnitude less than at the first and second mode frequencies.

c. An increase in S-IC propellant weight decreases the response in all of the first four modes, both at the payload and S-IC engine gimbal.

In comparing the Boeing AS-502 mode shapes to those for the AS-503 manned configuration (AS-503 Operational Structural Dynamics Characteristics, dated July 17, 1968) at T+120 seconds a trend was observed similar to that noted in comment "a" above. In that case, the AS-503 (manned) first mode gain factor* is 24% less than for AS-502 and the second mode gain factor 39% greater. In effect, the response has been shifted from the first to the second mode.

FREQUENCIES

The frequencies of the first four modes are given in Table III for both the baseline and weight variations. Trends are observed as follows:

a. Increased weight gives decreased frequencies, but with little change in the first and second modes.

b. A LM weight change makes the greatest change in the third mode, which is primarily one of LM response.

c. A SM weight change makes the greatest change in the fourth mode, which is primarily one of payload response.

TABLE III

FREQUENCY RESPONSE (CPS)
(T+120 SECONDS)

MODE	BASELINE	+10% SM WT.	+10% LM WT.	+5% S-IC PROP.
1st Mode	5.31	5.29	5.26	5.29
2nd Mode	6.40	6.40	6.37	6.39
3rd Mode	8.06	8.06	7.83	8.06
4th Mode	9.50	9.41	9.48	9.50

*gain factor = $\frac{(h_{gn})\ (h_{in})}{M_{eqn}}$, with symbols as previously defined.

CONCLUSIONS

It is concluded that:

a. Contrary to popular belief, changes in payload weight can make a significant change in <u>total</u> vehicle longitudinal response in the first and second body modes.

b. Changes in payload weight can make a significant change in the <u>payload</u> response in the third and fourth body modes.

c. Only minor changes will occur in the longitudinal frequencies due to changes in payload weight.

H E Stephens

2033-HES-mch H. E. Stephens

Attachments

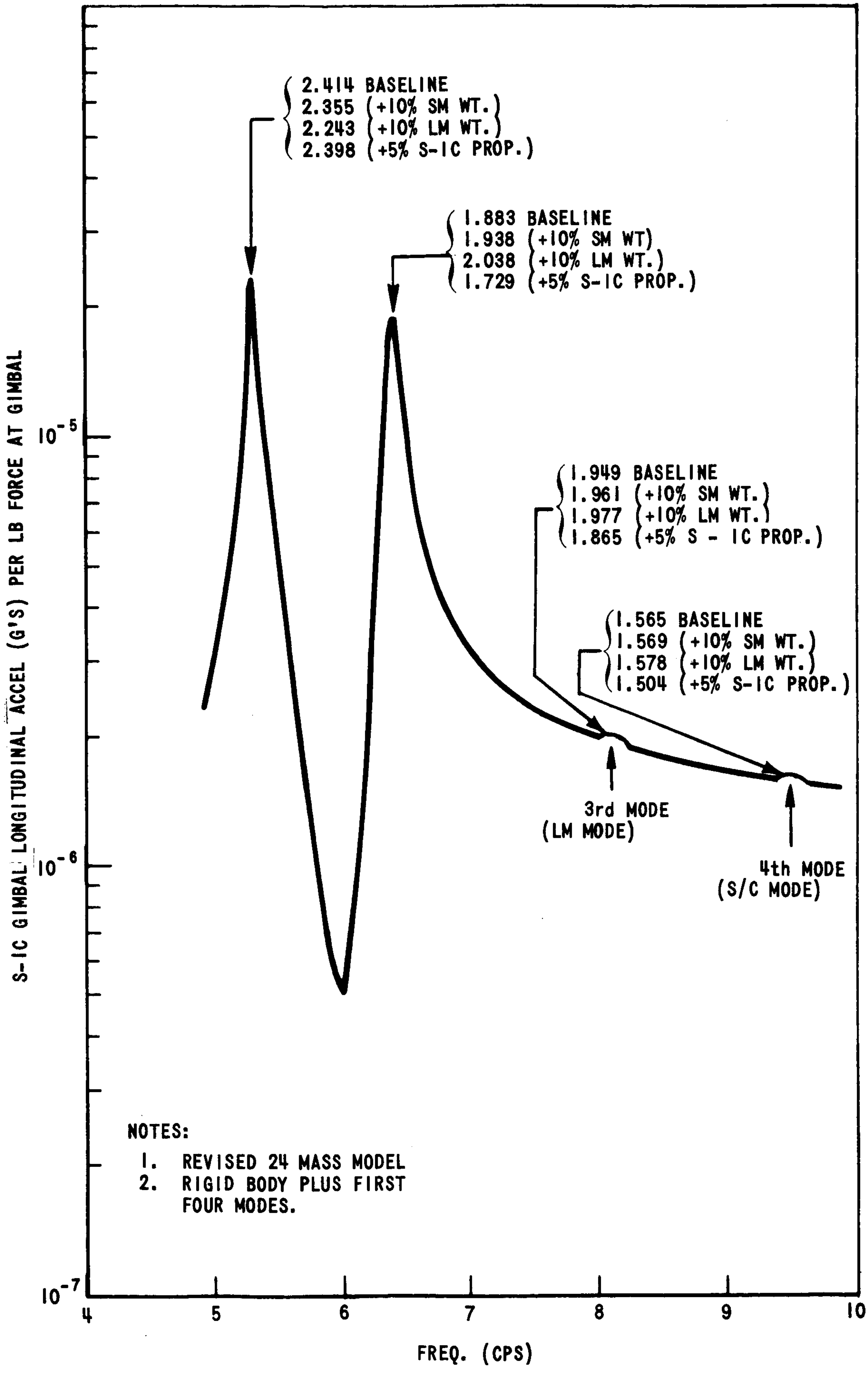

FIGURE 1 - EFFECT OF WEIGHT VARIATIONS ON GIMBAL LONGITUDINAL ACCELERATION RESPONSE T + 120 SECONDS

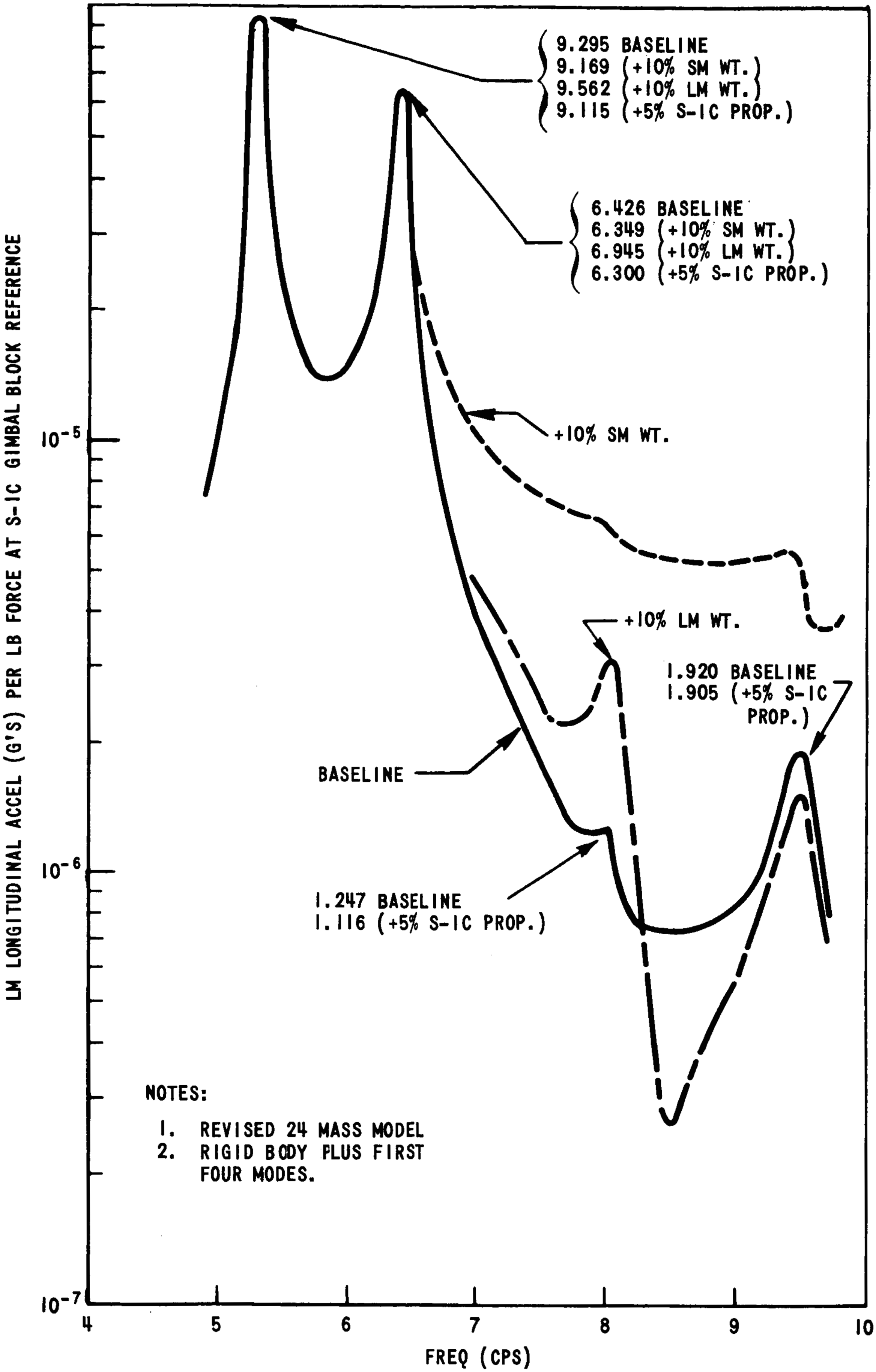

FIGURE 2 - EFFECT OF WEIGHT VARIATIONS ON LM LONGITUDINAL ACCELERATION RESPONSE T + 120 SECONDS

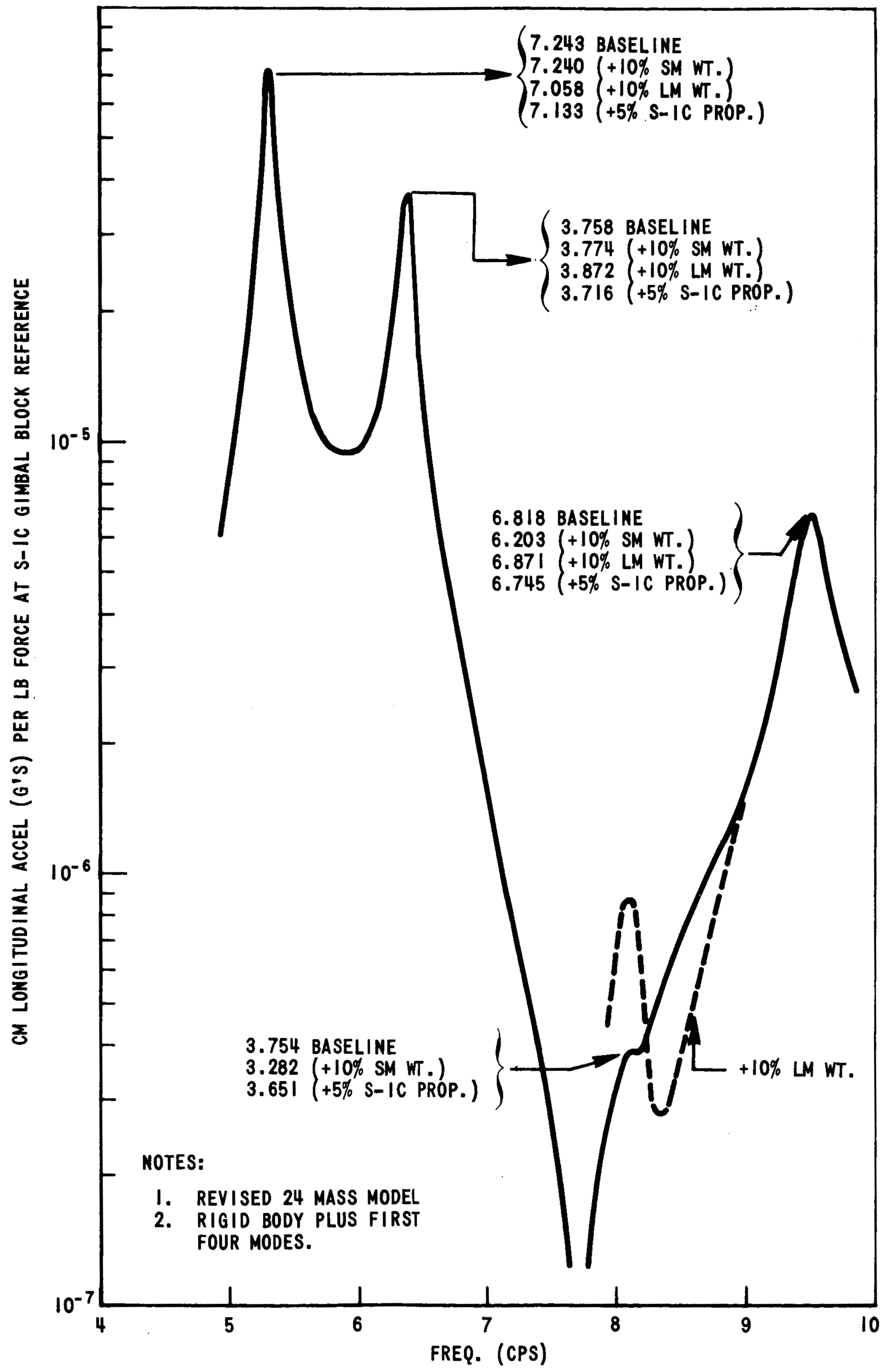

FIGURE 3 - EFFECT OF WEIGHT VARIATIONS ON CM LONGITUDINAL ACCELERATION RESPONSE T + 120 SECONDS

APPENDIX A

AS-503 (Manned)

24-MASS STRUCTURAL MODEL

INTRODUCTION

A 24-mass longitudinal model of AS-503, as shown by Figure 1A, was obtained from MSFC. The time varying weights of S-IC propellant used with the model are given in Table IA. This model incorporates time varying spring constants, which include both tank bottom response and tank wall bulge, to calculate the c.g. motion of the S-IC propellant. These time varying spring constants are given in Table IIA.

METHOD OF SOLUTION

This simplified model was placed in operation to do a parametric study on the effect of payload and fuel load variations on longitudinal frequencies and mode shapes. Solutions for the frequencies and mode shapes were obtained as follows*:

a. Problem formated as:

$$\left[\underbrace{M^{-1/2}\ K\ M^{-1/2}}_{\text{Symmetric}} - \lambda I\right]\left\{x\right\} = 0^{**};$$

The mode shape coordinate h is related to x as:

$$h = M^{-1/2}x$$

b. A non-iterative method was used to solve for the eigenvalues and eigenvectors as follows:

   1. The symmetric matrix was transformed to a tridiagonal one by Householder's method.

   2. The eigenvalues of the tridiagonal matrix were obtained by Sturm sequences.

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*All computer programming was performed by F. Brewer of Department 1032, Bellcomm.

**Credit for this format is also to F. Brewer.

TABLE 1A

AS-503 S-IC PROPELLANT WEIGHT (LBS)

Time (Seconds)	M18 S-IC LOX	M19 S-IC Fuel
0	3,023,212	1,319,307
10	2,817,841	1,227,373
20	2,614,030	1,139,122
30	2,409,769	1,050,793
40	2,205,022	962,395
50	1,999,702	873,920
60	1,793,899	785,360
70	1,587,705	696,723
80	1,380,610	607,918
90	1,172,436	518,918
100	963,230	429,728
110	753,099	340,348
120	542,028	250,781
130	329,686	160,983
140	134,319	78,141
149	2,736	15,563

TABLE 11A

AS-503 S-IC TANK BOTTOM STIFFNESS

Time (Seconds)	K_{LOX} (K_{17})	K_{Fuel} (K_{18})
0	4.20	6.70
10	4.60	7.30
20	5.20	8.00
60	8.30	13.80
90	14.60	20.60
100	19.40	100.00
110	100.00	100.00
120	100.00	100.00
130	100.00	100.00
140	100.00	100.00
149	100.00	100.

Note:

Stiffness in (lbs/inch x 10^{-6})

3. The eigenvectors of the tridiagonal matrix were obtained by Wilkinson's method.

c. Eigenvectors were normalized to an equivalent mass of 1 lb-sec^2/in.

MODEL COMPARISON AND REVISION

Frequencies and mode shapes obtained were compared with those of "AS-503 Operational Structural Dynamic Characteristics" dated July 15, 1968, by the Boeing Company. (Two time points were used for comparison, T+00 and T+120 seconds.) Observations were:

a. 3rd Body Mode. This mode is primarily one of LM motion and its frequency remains constant at 8.09 cps throughout S-IC boost in the Boeing study. The frequency of this mode was constant at 8.45 cps in the 24 mass-model results.

b. 4th Body Mode. This mode is primarily one of motion of the payload and its frequency remains constant at 9.57 cps throughout S-IC boost in the Boeing study. The frequency of this mode was constant at 8.38 cps in the 24-mass model-results, or less than that of the 3rd body mode.

Because the major differences were in the 3rd and 4th body modes, the spring constants connecting the payload masses were examined to determine the feasibility of forcing the 3rd and 4th body modes of the 24-mass model into agreement with those of the Boeing study. This was done as follows:

a. Reference time: T+120 seconds

b. Boeing vector coordinates corresponding to the 24-mass model mass locations and frequencies were used in the 24-mass model to calculate new K's.

Changes in K's (see Figure 1A) were as follows:

TABLE IIA

K Number (Figures 1A)	Old Value	Revised Value
1	0.865×10^{-6} lb/in	1.0×10^{-6} lb/in
2	1.42	1.6
3	2.20	2.5
4	1.15	1.1
5	0.23	0.20
6	3.9	4.5

Comparative plots of the first tank and first four body modes at T+00 and the first four modes at T+120 seconds are given by Figures 2A through 10A. The revisions of the 24-mass model accomplished the following:

a. Shifted the 3rd body mode frequency from 8.45 to 8.06 cps (8.09 Boeing).

b. Shifted the 4th body mode frequency from 8.38 to 9.50 cps (9.57 Boeing).

c. Brought the LM response in the 3rd body mode in agreement with Boeing results.

d. Brought the spacecraft response in the 4th body mode in agreement with Boeing results and improved correlation of launch vehicle coordinates.

e. Made minor improvement in correlations of the first and second body modes.

CONCLUSIONS

It is concluded that the revised 24-mass model provides an adequate baseline for the parametric studies. There has been much discussion concerning the use of the 24-mass model results for stability studies. From Figures 7A and 8A, it can be seen that the 24-mass model predicts higher modal coordinates in the critical first and second modes than does the more complex Boeing model. Hence, use of the Boeing mode shapes will predict smaller gain factors and greater stability margins than would use of the 24-mass model mode shapes.

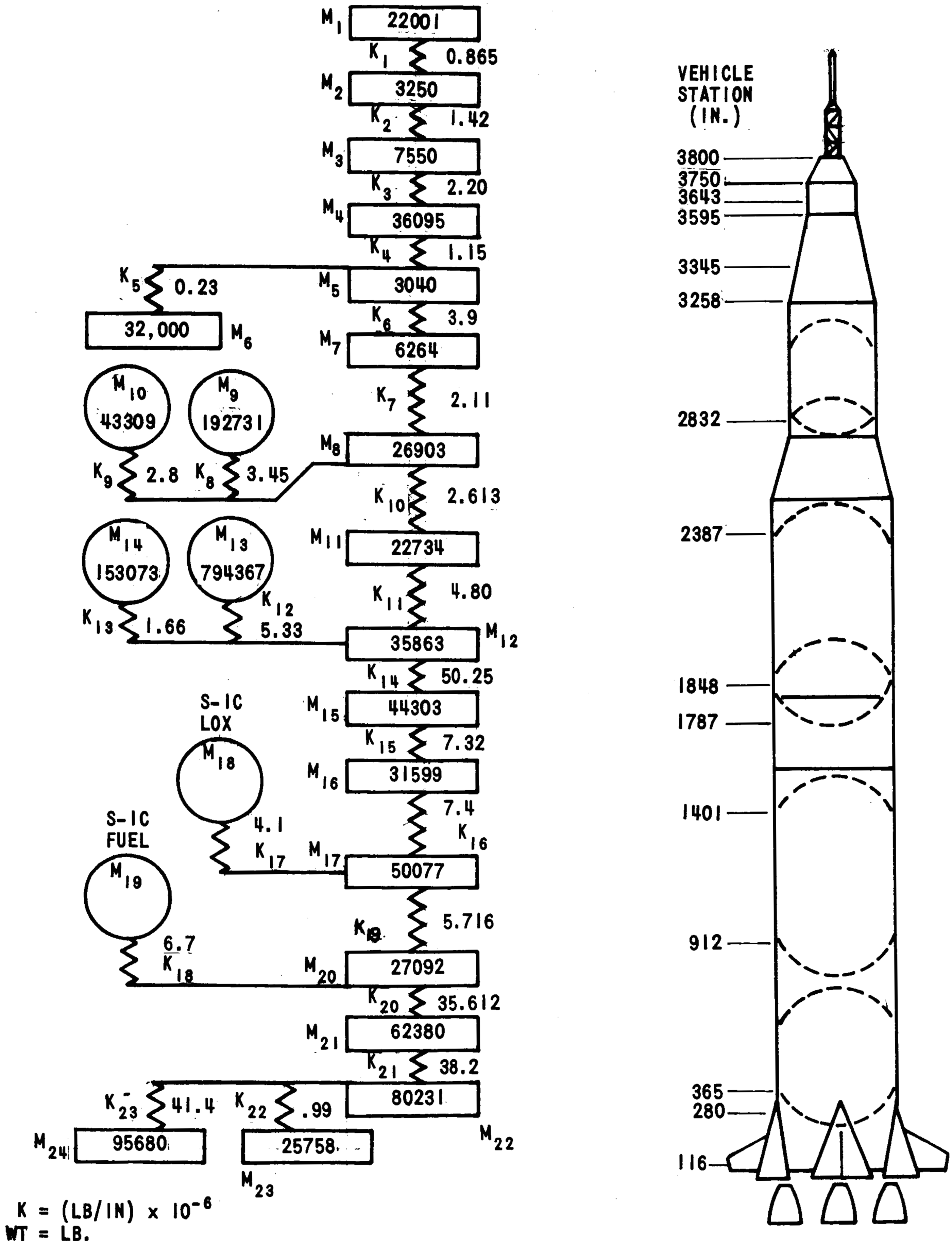

FIGURE 1A - AS-503 24 MASS LONGITUDINAL MODEL

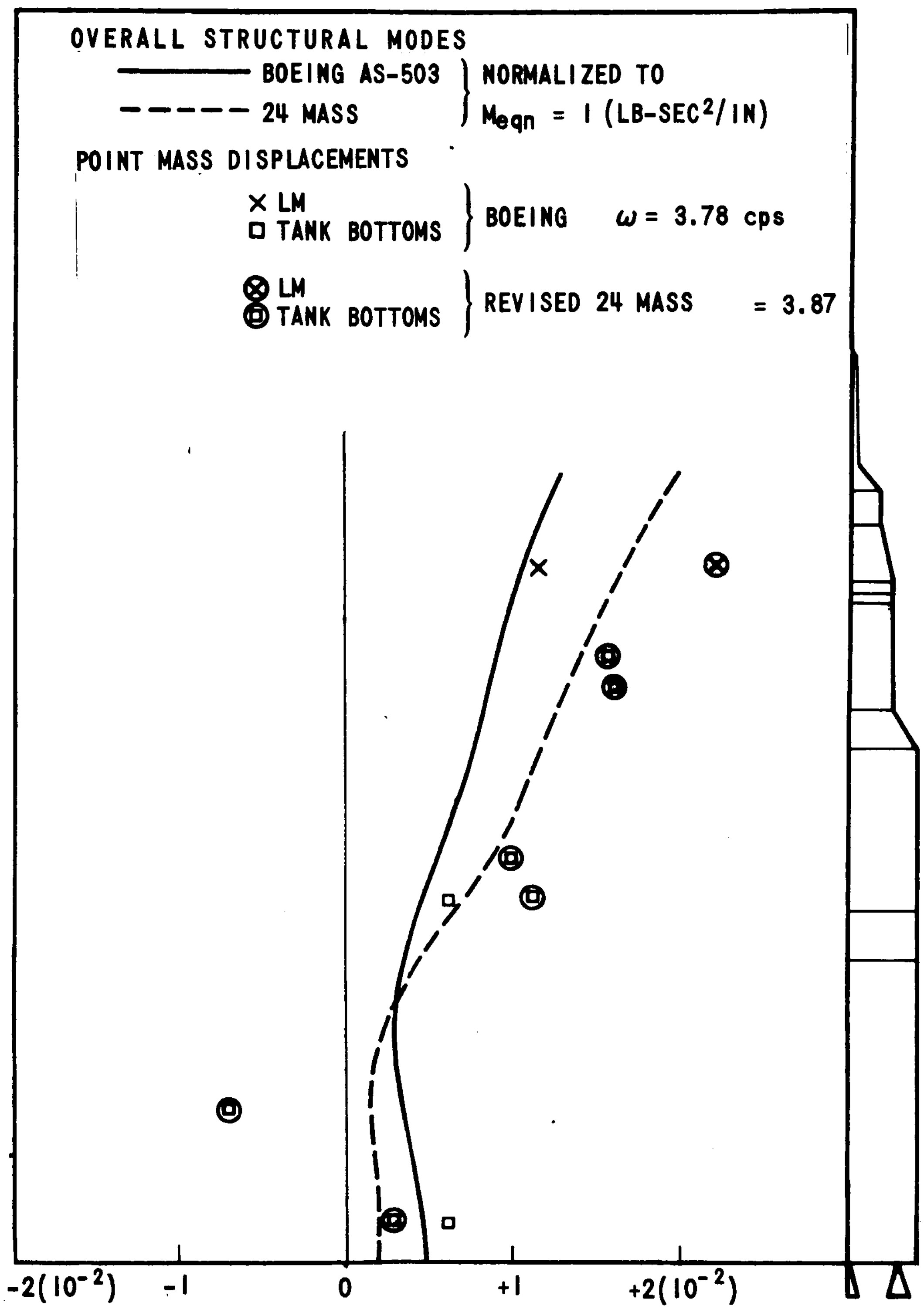

FIGURE 2A - AS-503 LONGITUDINAL MODE SHAPE FIRST TANK MODE AT T + 00

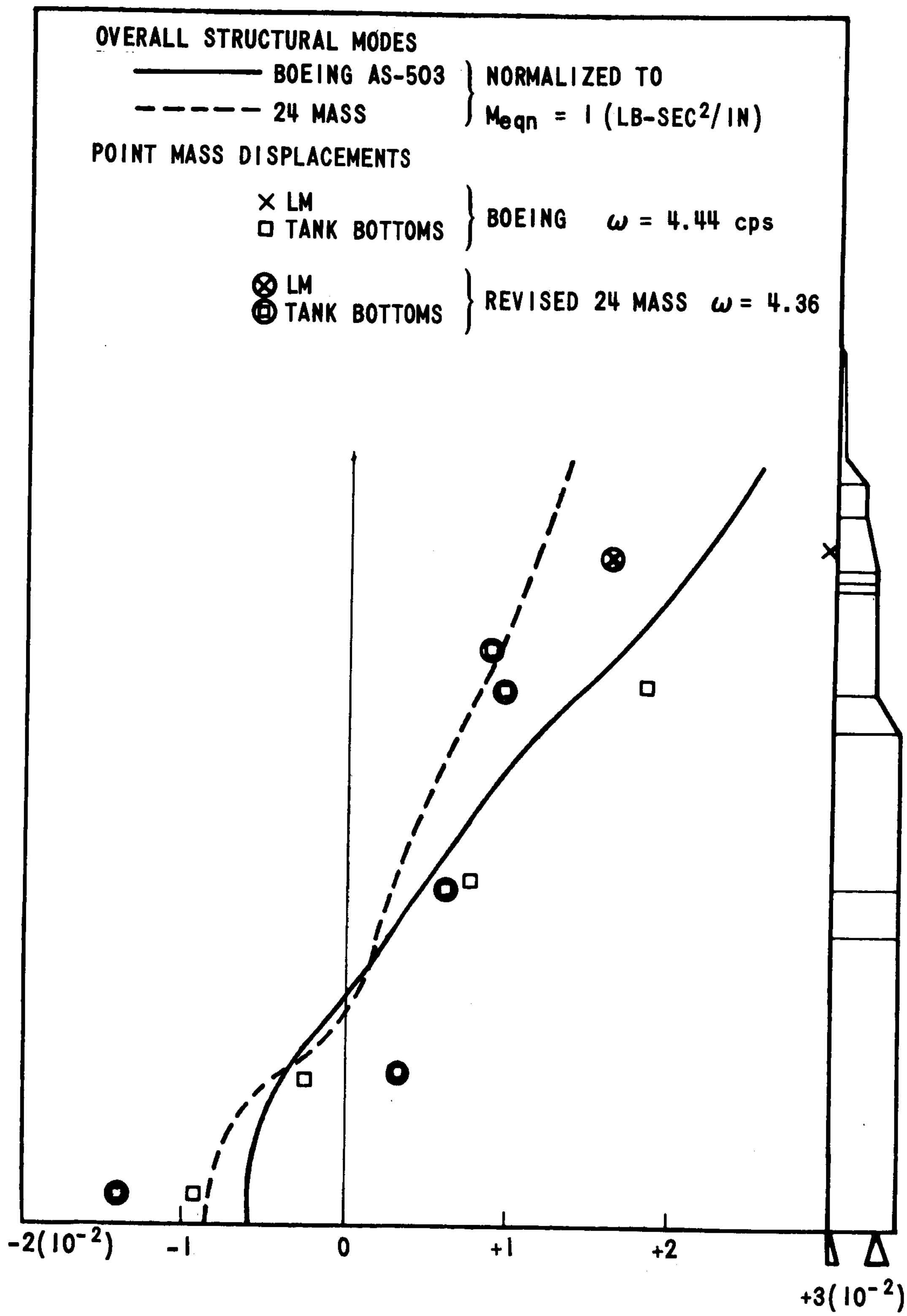

FIGURE 3A - AS-503 LONGITUDINAL MODE SHAPE FIRST BODY MODE AT T + 00

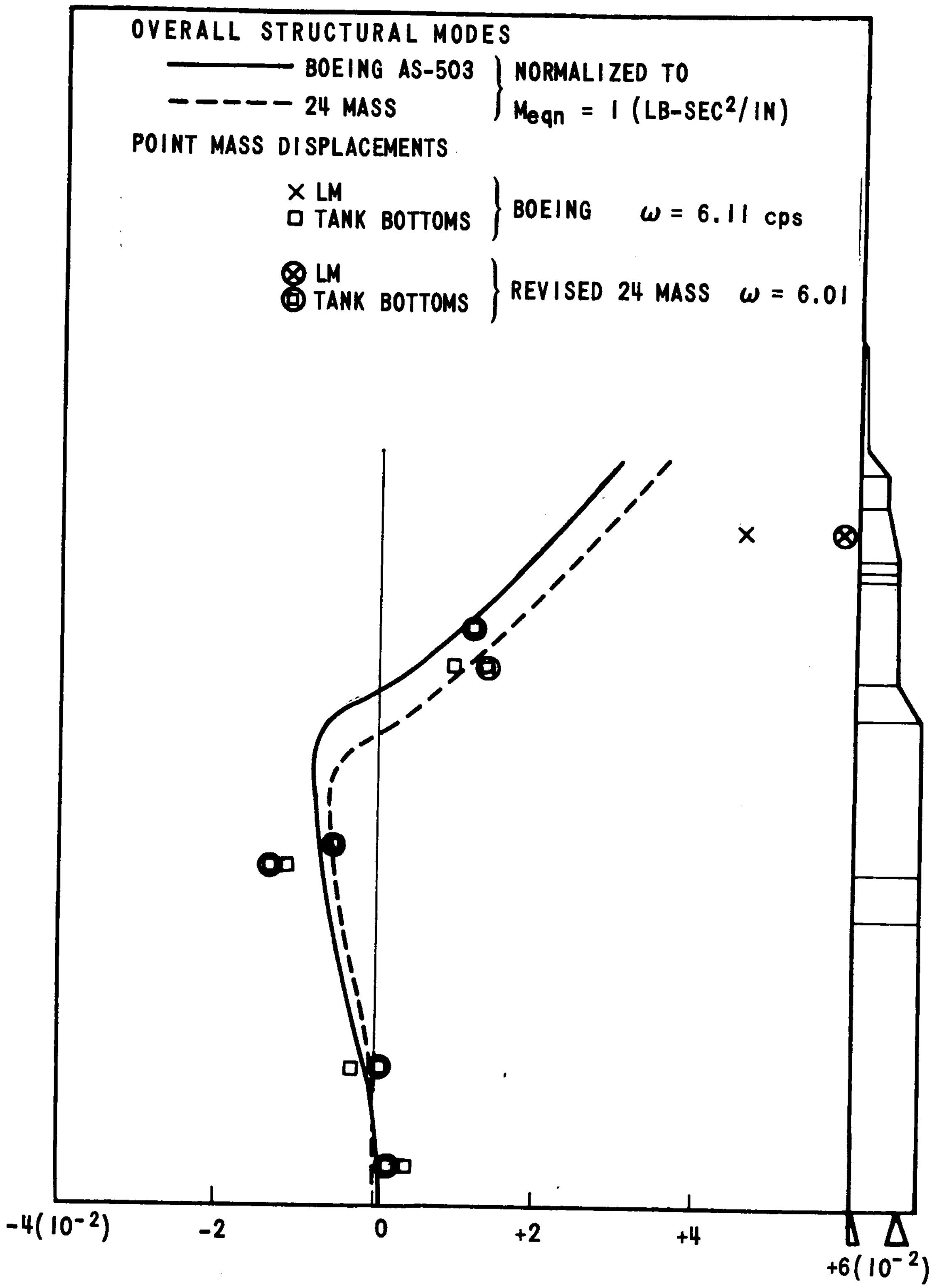

FIGURE 4A - AS-503 LONGITUDINAL MODE SHAPE SECOND BODY MODE AT T + 00

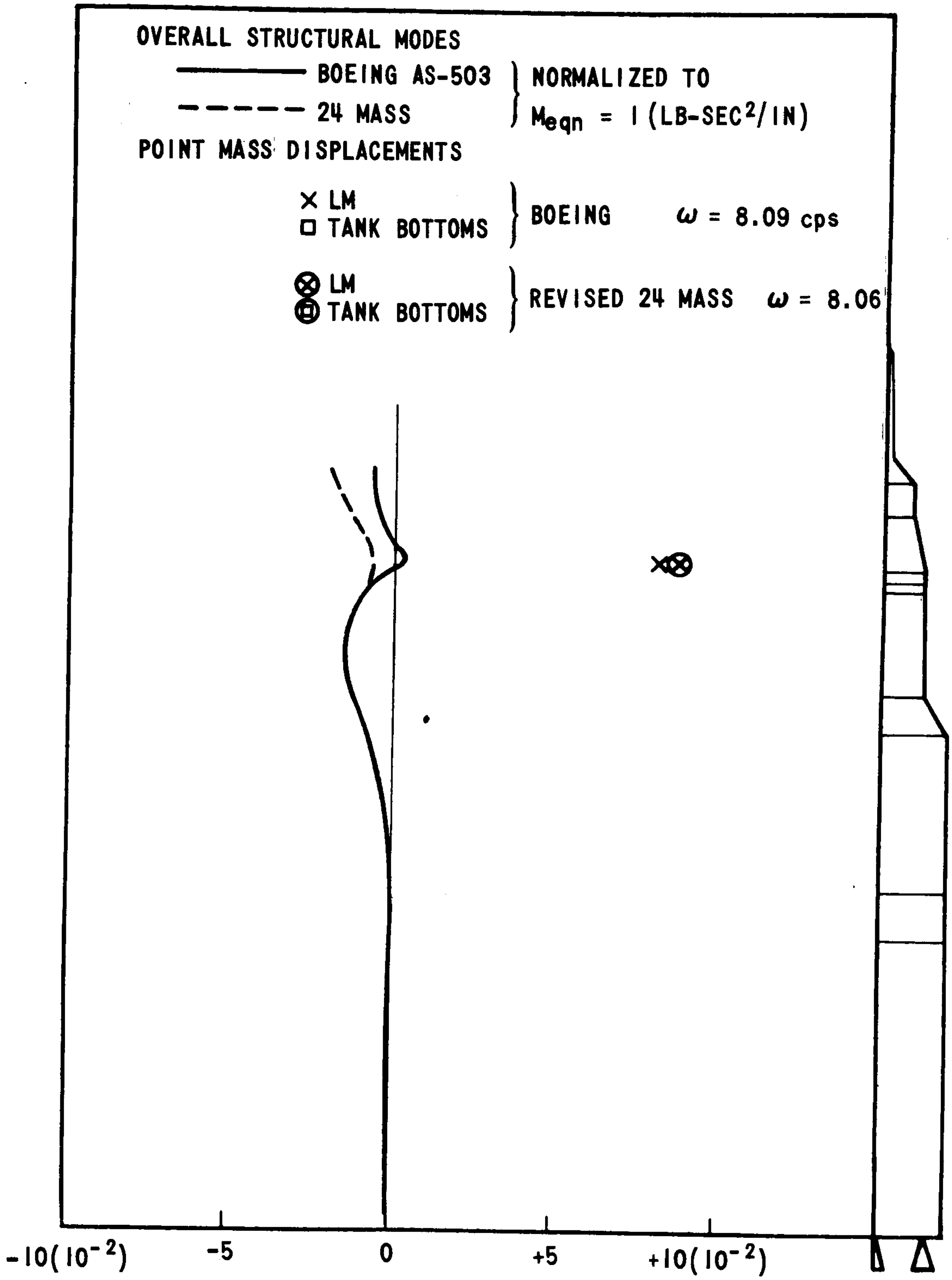

FIGURE 5A - AS-503 LONGITUDINAL MODE SHAPE THIRD BODY MODE AT T + 00

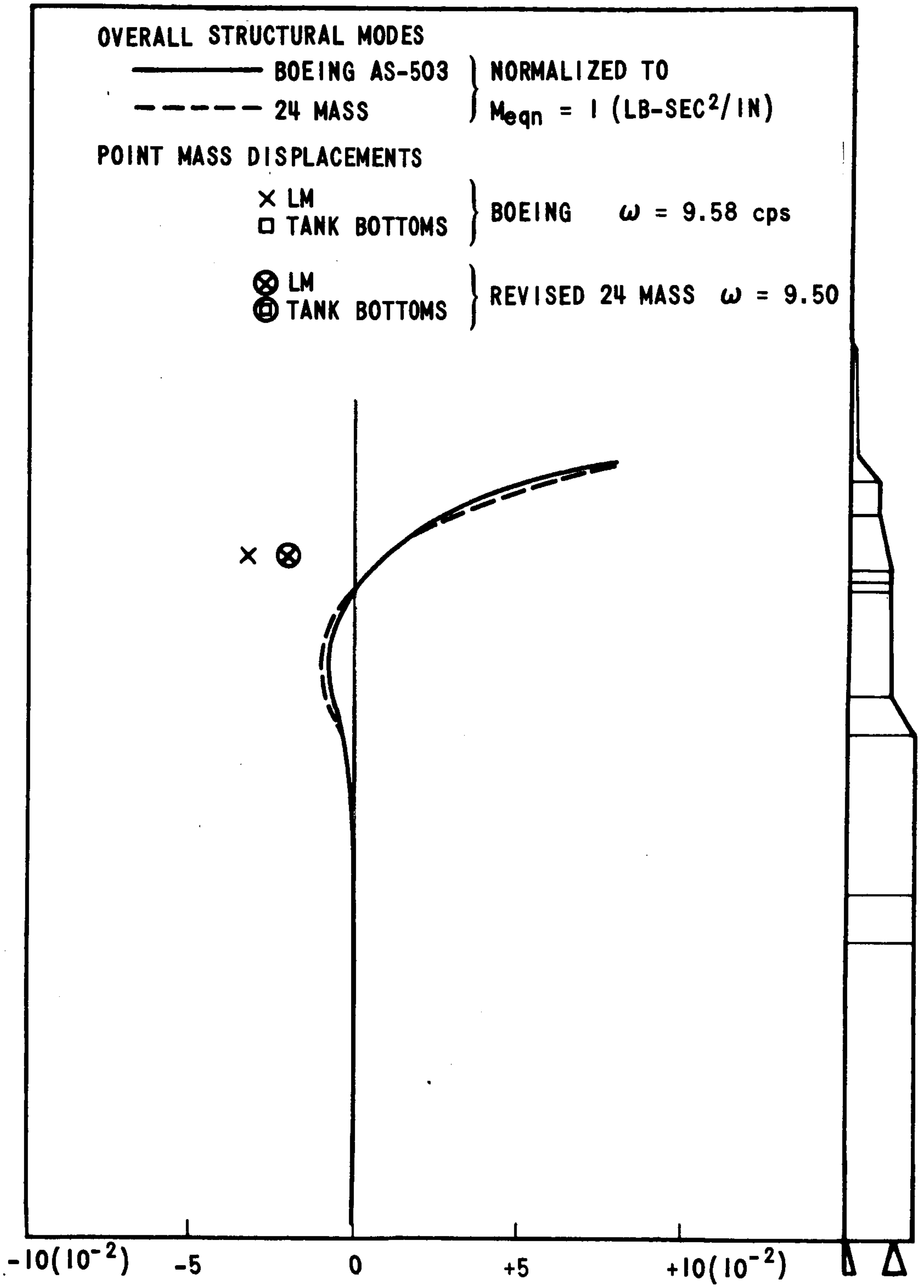

FIGURE 6A - AS-503 LONGITUDINAL MODE SHAPE FOURTH BODY MODE AT T + 00

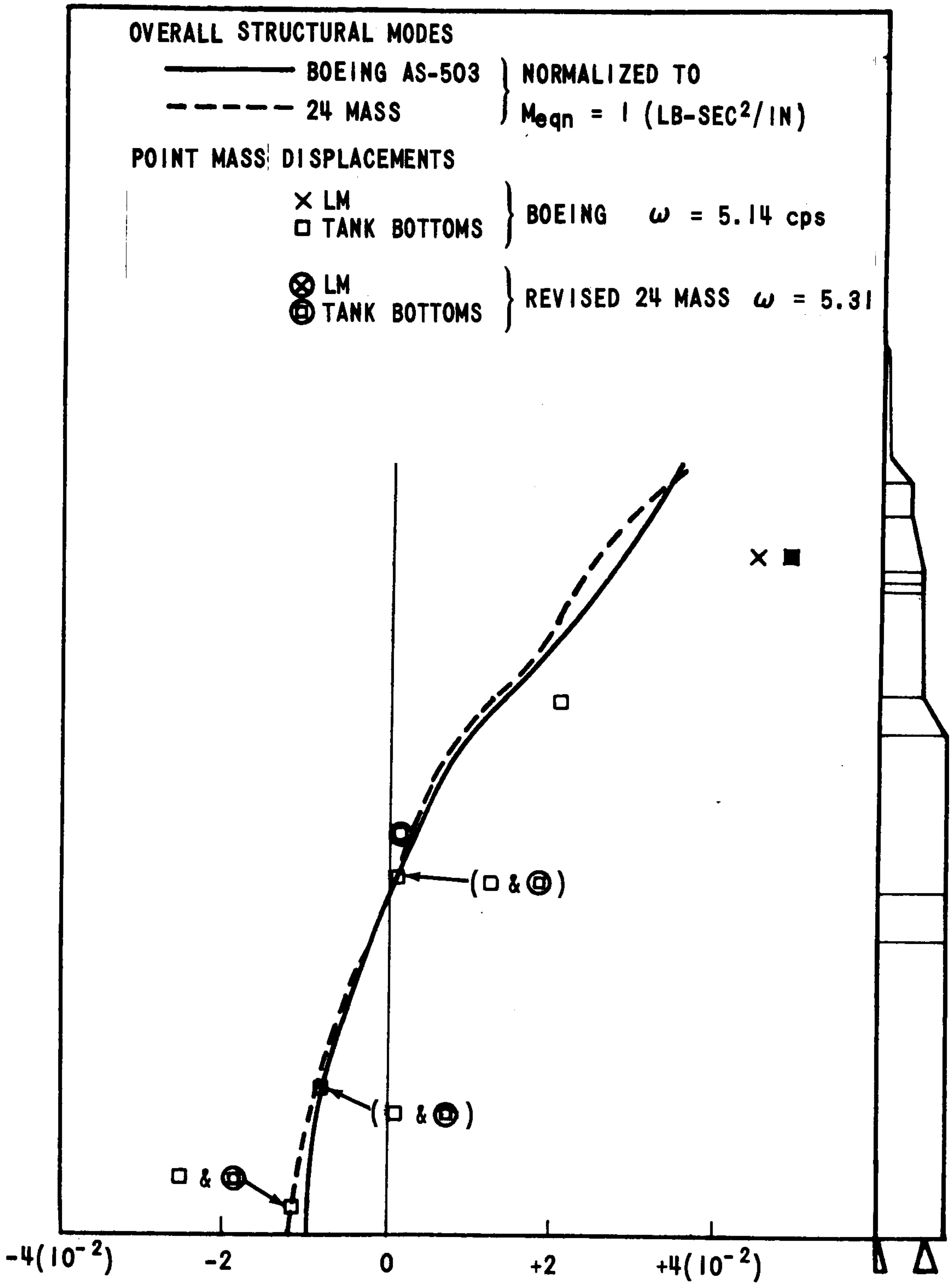

FIGURE 7A - AS-503 LONGITUDINAL MODE SHAPE FIRST BODY MODE AT T + 120

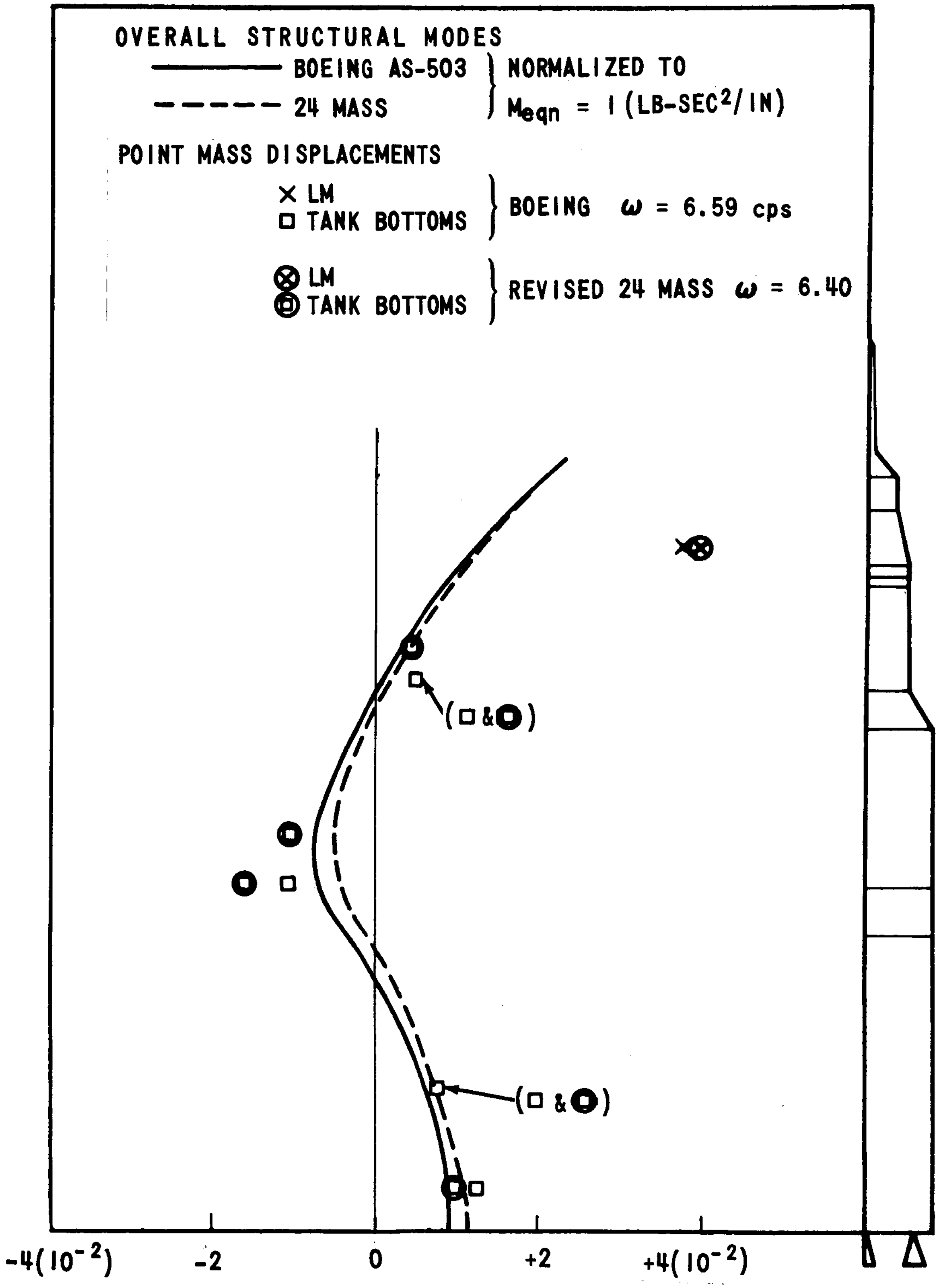

FIGURE 8A - AS-503 LONGITUDINAL MODE SHAPE SECOND BODY MODE AT T + 120

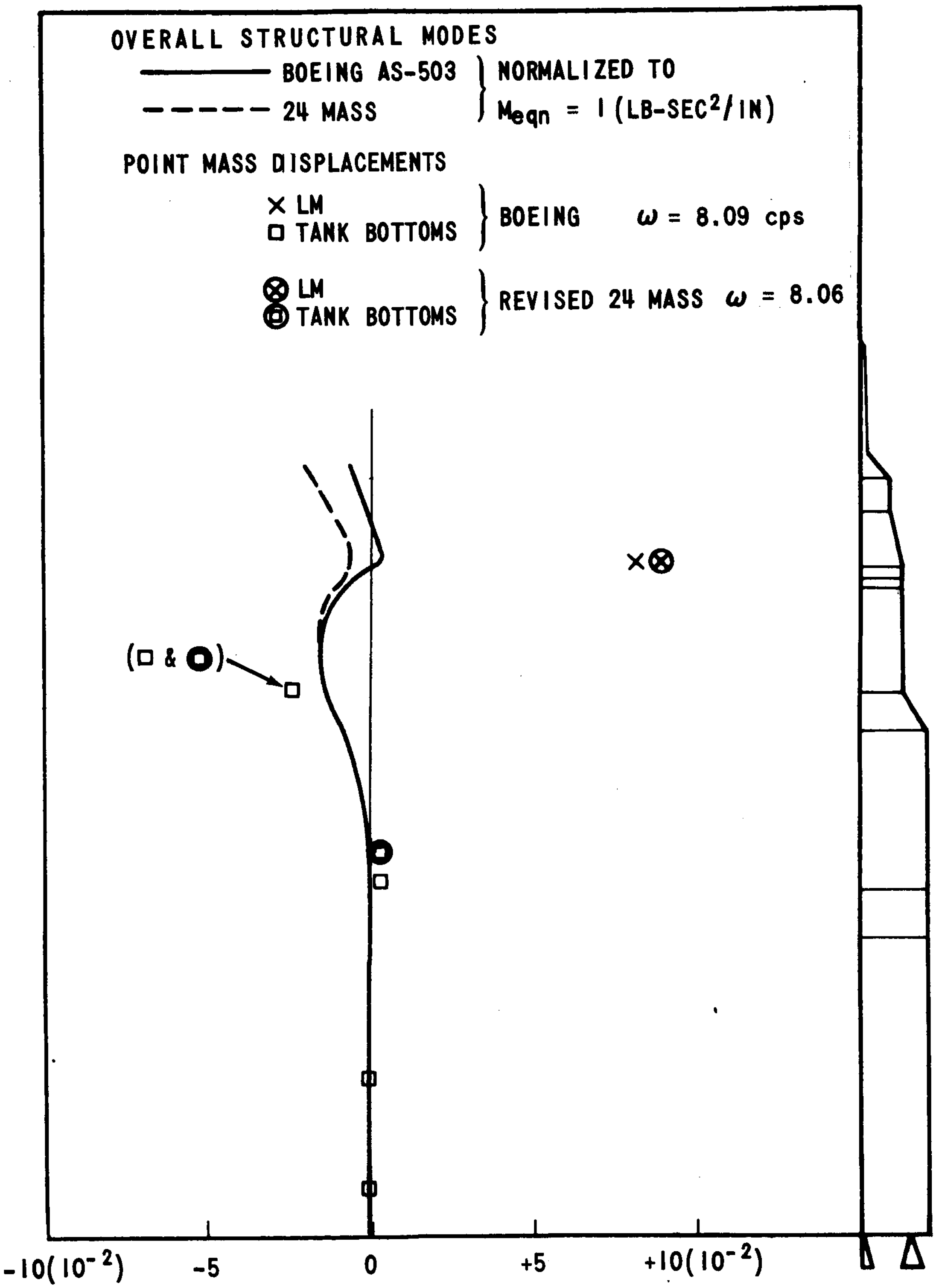

FIGURE 9A - AS-503 LONGITUDINAL MODE SHAPE THIRD BODY MODE AT T + 120

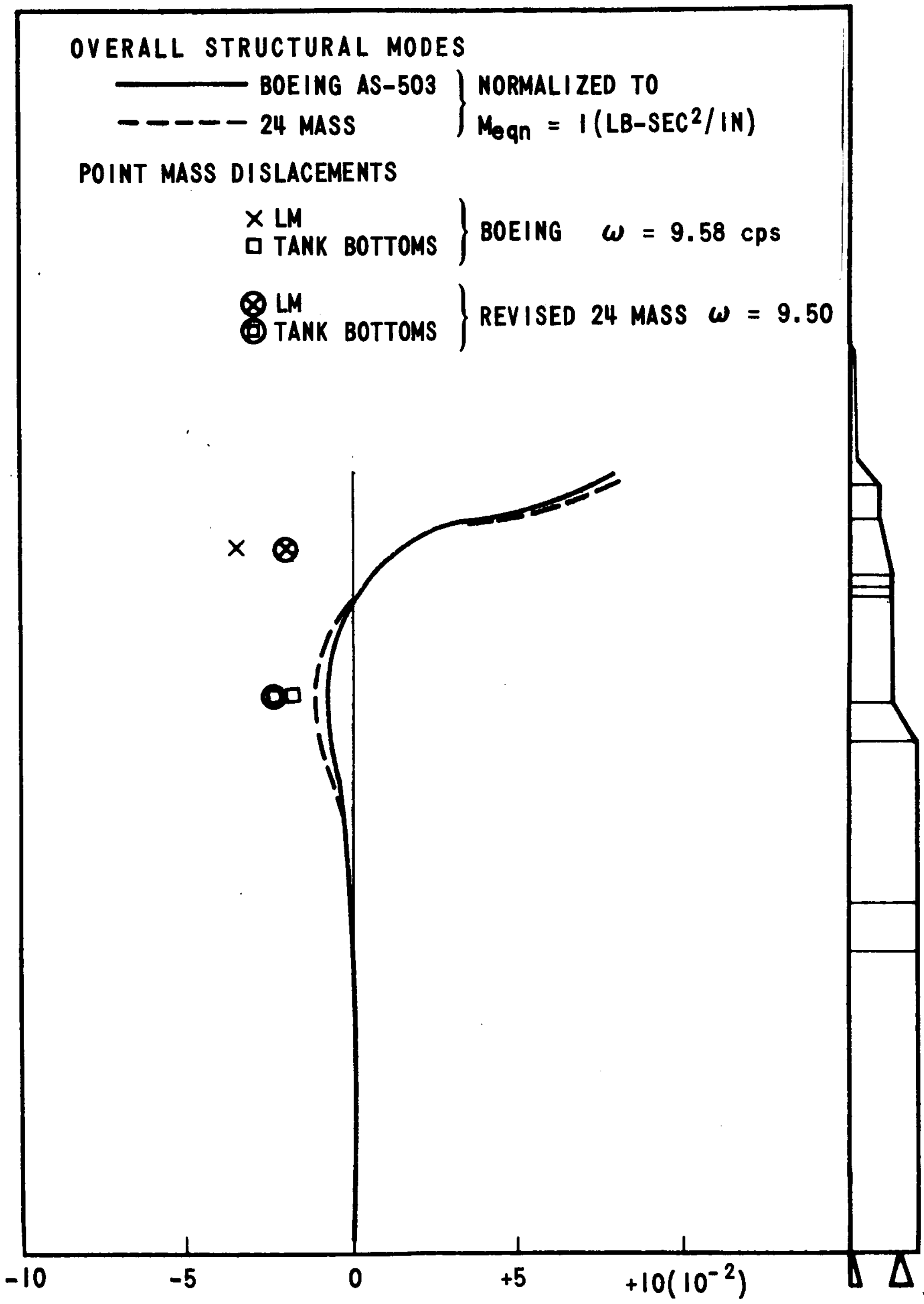

FIGURE 10A - AS-503 LONGITUDINAL MODE SHAPE FOURTH BODY MODE AT T + 120

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